METAL CASTING

Implementing the lost wax and waste mold gravity process of metal casting in the public school art program.

A Paper Submitted in Fulfillment Of The

Requirements

In

Problems In Art Education 295

By

Rodger C. Hansen

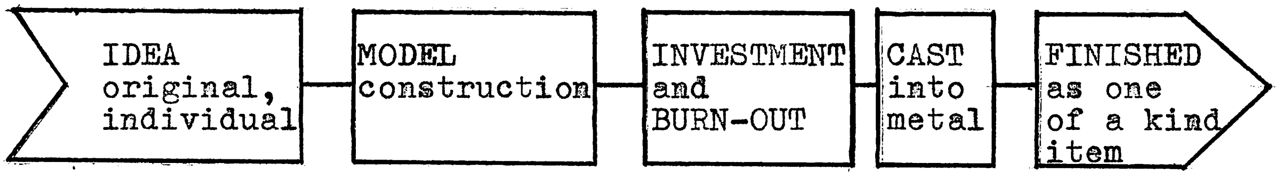
University of Minnesota - Duluth

August 22, 1969

CONTENTS

This written text with related slide illustrations is a unit prepared for audio-visual adaptation and correlation for presentation to fellow art teachers or advanced art students of the senior high school level and above. The purpose of this text is not to relate to the history or the numberous approaches to casting in metal. Rather, it is intended as an orientation to the actual fulfillment of the lost wax and waste mold process. The full realization of casting in metal will then occur when the student goes through the process by personal involvement. With experience and experimentation one can go beyond the context of this unit. Formulary and other data have been included to further acquaint the novice with the exercise described.

Metal casting need not be a difficult process. It is not an area to be disregarded when supervising capable art students in the senior high school. It does however involve critical steps toward completion, when one goes beyond simple sand casting or lead puddling processes. For this reason I have provided slide illustrations which are intended to go beyond word of mouth or written and diagrammatical explanation. The illustrations were taken during my personal involvement in casting Bronze. Thus some of the examples may be larger and more complex than expected of high school student artists. However they do serve in visually explaining possibilities and problems involved in a basic metal casting exercise. Appendix A will give the novice a brief visual outline of the process. Appendices B through H will list related data.



The above diagram and that of Appendix A will serve as an introductory explanation of this exercise. Cultivating an understanding of positive and negative space reflected light, volume, weight and further knowledge of three dimensional design is an important prerequisite to such involvement. However it should be assumed that students selected for this project be proven capable in more rudimentary sculptural experiences. They will find metal casting a particularly exciting experience, producing forms of great strength and of a lasting quality. A wax model is constructed which is then surrounded by an investment mixture of plaster, silica sand and powdered silica (other formulas are listed in Appendix D). When dry the invested form is heated, eliminating the original wax model, through the processes of steam-out and burn-out. The resultant hot hollow form is then impacted in an earth environment, filled with molten metal and allowed to cool. The investment is then broken away, freeing the solidified metal replica of the formed wax model. Excess ductwork and flashings if any are cut away. The cast is scrubbed clean, or in rare instances sand-blasted. Finally the work is surface colored with chemical agents, emerging as a one-of-a-kind item (formulas listed in Appendix G).

Before elaborating on the process of metal casting, I wish to make mention of the maxim - "Safety First". High temperatures are encountered in melting wax, evaporating wax, heating the mold and in handling of molten metal. Although this exercise need not be more dangerous than working with scissors, strict safety precautions must be observed. Use of a variety of tools is necessary to finish the cast form. The student must present a working knowledge of such equipment. When working with hot wax one must be careful not to let it over-heat. Water must never be allowed to mix with heating wax. Waxes such as paraffin must never be heated directly over a flame but rather in a double boiler, permitting indirect heating. One handling hot molds or hot metal must be clothed with asbestos or other heat retardant material. In the case of power tools, goggles must be worn to protect the eyes from debris. Coloring the final cast begins with careful preparation of chemical agent formulas by the teacher. Rubber clothing is desirable. After preparation these will not be dangerous to handle as they will all be diluted mineral formulas. Always add acid to water. The reverse process could result in a violent chemical reaction. Student application in all steps must be supervised by a qualified instructor. First aid materials must be at hand to cope with the unexpected.

(Figure 1)

Eleven basic steps are involved in this particular approach to casting. They are as listed:

1. Construct Model
2. Sprue and Vent Model
3. Debubblize Model
4. Invest Model
5. Burn-out Model
6. Set Mold in Sand or Earth Base
7. Pour Molten Metal
8. Remove Investment, Sprues and Vents
9. Grind and Chase Casting Surface
10. Patina (Coloration of the cast form)
11. Mount on Base (Completion of the form)

For the sake of convenience and clear explanation, we will follow the casting process within these generalized topic areas.

I. Construction of the Model

Many different waxes are possible for implementing the construction of the model. Common art supply houses will usually offer a selection of sculptural waxes. With experience one might find that which presents properties most suitable for his particular needs and deal in bulk with a variety of petroleum companies and chemical supply houses. Those waxes which have the greatest qualities of plasticity, strength and stability are of course best.

The model may be formed by carving, drilling, filing, grinding and/or melting the hardest waxes to the desired shape. More plastic waxes may be modelled directly at room temperature with special effects gained from hot and cold water immersions.

Most any formerly discarded implement may serve as an excellent wax modeling tool. Old dental spatulas, eating and manicure utensils and pocket knives are but a few of these possibilities. Others may be improvised. A five to six inch length of heavy wire, planished and polished at the top will serve as an excellent spatula. A common pin fixed to a section of doweling, with head clipped or ground away makes an excellent implement for detail work. Improvise. (Figure #2)

Represented are basic preliminary tools - a sketchpad and pencil for recording ideas, modeling tools and modeling wax. An electric hot plate or gas supply will serve as a means of warming the wax to desired workable stages. Never heat waxes such as paraffin directly over a flame as they are highly combustible. Use of such waxes if necessary will require the use of a double boiler and undiverted attention. As mentioned previously a variety of casting waxes are readily available. Although they are considerably more expensive than paraffin they are worth there price for safety reasons; many of them are relatively noncombustible. One may prepare his own wax from a wide selection of sculptors' and dentists' formulas, but the procedures are very time consuming, requiring much space and are impractical in supplying the needs of a sizable number of students.

A wax model is taking form in this example, constructed of thin strips of plastic wax. Providing thin sheets of wax to facilitate this particular approach is a simple process. By placing a damp cloth or paper on a ridged tray or similar flat surface, bulk hot wax can be poured to any desired thickness. When cooled and solidified, the sheet of wax is easily removed. This procedure is particularly desirable in supplying workable supplies of plastic wax to students as desired quantities are easily torn away from the sheet and worked into other shapes. It is best to note when constructing the model that areas of less than one-quarter inch and more than one inch in thickness are most likely to encounter difficulty in the casting process. Mold passages after burn-out that are too narrow are most likely to encourage the molten metal to freeze or solidify before filling all desired areas. Those passages that are too thick will show evidence of metal shrinkage when the molten material cools and solidifies.

(Figure 3)

A completed wax model is ready for sprueing after one is certain that any appendages are adequately fused to the main body. This is often facilitated by brushing liquid wax to the joins.

II. Sprue and Vent Model

A series of three examples will serve to illustrate the actual process of sprueing and venting the model (according to particular demand.) Sprues are constructed wax channels through which molten metal may eventually reach all areas of the intended cast form, following the burn-out phase. Similarly vents are wax passageways which will eventually serve to eliminate otherwise trapped gases during the pouring of molten metal.

(Figure 4)

As this is a relatively large and complex form, approximately ten inches high, smaller projects have been added doubling as auxiliary sprues. Thus matters have been simplified in that three models will be cast from one investment or mold.

(Figure 5)

This unit is prepared as if it were two individual projects. The container portion is separated from the figurative lid by a trunkated sprue. As a number of thin areas are present, auxiliary sprues are required to insure molten metal will flow throughout the assembly. One can over sprue but his chances of an incomplete cast are fewer. Consideration must be given though that these pliable wax channels will eventually be transformed into inflexible metal. As they will have to be sawn away, thought must be given to their positioning to facilitate their removal after casting.

(Figure 6)

This model has a thick volume for its base. It must be constructed of thin sheets of wax and the hollow filled with investment becoming a core. Pins will be inserted into the core through the wax, enabling it to be supported by the outer investment once the wax is eliminated in burn-out. As mentioned earlier, if this lower volume were cast in a solid mass considerable contraction of the metal upon cooling would result in a distorted form.

The completed wax assembly is next weighed. A previously determined ratio of wax to metal will then be applied when preparing for the metal melt. For example a normal equivalent of aluminum would be three times as heavy as the wax. The ratio of wax to bronze is 1:10.

III. Debubblize Model

(Figure 7)

A thorough coating of commercial debubblizer or green soap is brushed onto the wax assembly to eliminate any surface oils that may resist investment application. Wax areas that would not permit investment to hold would result in deformities in the cast as pos~~s~~itive bubbles. Care must be taken in applying the debubblizing agent, just prior to investment to insure lather or soap bubbles are not created or allowed to remain on the wax surface. Should either of these factors happen they must be gently brushed or blown free. Otherwise they too would contribute deformities in the cast as pock marks.

IV. Invest Model

Investment is a mixture of binding and refractory ingredients formulated to set with a hard smooth contact to the wax model. Many recipes are possible in this stage of metal casting, some of which are listed in Appendix D. The dry ingredients are added to water until a thick creamy consistency is achieved. One should not mix in the reverse manner for this would only result in an unmanagable lumpy mass. On completion of the burn-out state, the hollowed investment will have become a negative mold into which molten metal will be poured.

(Figure 8)

The two basic formulas for investment are listed in parts by volume. The first coat will consist of one part powdered silica (brick dust may be substituted), one part plaster, and one part silica sand. These components are added to water until a creamy consistency is achieved. The mixture should then be brushed on the model insuring that all detail is covered well. Subsequent applications may be trowelled on. The second formula is comprised of one part luto or previously fired, finely meshed investment, one part plaster, and one part silica sand added to water. This outer coating aids in the refractory property of the total mold, but would be too coarse for first coat detail application.

(Figure 9)

The first coat dry components are illustrated in their similarities. For this reason the container sources of powdered silica, plaster and silica sand must be adequately labelled. The student-artist must be alert and conscious of his mixing procedure to insure proper preparation.

For the most part wax models can simply be covered with investment layers and allowed to dry in preparation for steam-out and burn-out (See Appendix A). However, more complex forms require special steps in investing. At this time I should like to follow two projects in this latter category through investment procedures. The first example, having a large volume displacement, will be one requiring an inner core of investment. The second having many negative areas, will require construction of an outer flask.

(Figure 10)

This form has a bottom area displacing several inches in both height and width. The form was made hollow and filled with investment, creating an inner core. Pins were then inserted into the core through the wax with enough pin surface protruding to permit the outer investment layer a firm grip. After burn-out the core will be suspended within the mold only by these common pins. Larger forms would require heavier rod to serve as pins.

(Figure 11)

The first coat of investment is brushed on carefully making positive contact with both the detail of the wax and of the protruding pin surfaces.

(Figure 12)

The second coat formula is now applied, permitting hand and tool trowelling. This procedure is done while the first coat is still moist to prevent any separation of investment layers.

(Figure 13)

The invested form is complete, ready for steam-out. Note the wire mesh reinforcement used in the second coat application.

(Figure 14)

The invested form or mold is allowed to dry thoroughly; in the case of larger works sush as this several days may be required. The dry mold is positioned to where the wax pouring cup is the lowest part of the total. A bunsen burner or hot plate is used to heat a tea kettle, two thirds full of water. A plug in the spout with hose attached facilitates transfer of the resultant steam to the wax opening. Reclamation of much of the wax is thus possible prior to burn-out. This step is optional but worth the time and effort in money saved for future castings.

(Figure 15)

This wax model of a head, with numerous negative areas, would present a problem in attempting simple direct application of investment. One could not be certain that all open areas would readily receive investment completely. Thus this particular project requires investing in reverse. The model is measured and a cylindrical flask is prepared for it allowing approximately one inch clearance in all directions when completed. Heavy wire mesh is utilized in forming the basis of the flask. The second coat recipe is used.

(Figure 16)

A large quantity of second coat dry ingredients is prepared in a sizable tub. As creation of the flask will require much of this material, time will be saved by this preliminary process. The proper procedure in mixing the ingredients is shown, sifting the dry compound into the water. As mentioned earlier, adding water to the dry ingredients would result in an unmanagable lumpy mass.

(Figure 17)

The flask is built with the screen serving as an armature. The investment is applied when an even heavy sludge is achieved. This permits an easy bond to the screen.

(Figure 18)

A gas elimination hole is drilled from the flask floor. A wax plug on the top of the wax model will later be fit into this hole.

(Figure 19)

The final stage of flask construction has been reached when the walls are approximately one-inch thick. Smaller projects might make use of a coffee can or similar item. Cutting out both ends and severing the wall would be an asset in final discard of the mold.

(Figure 20)

A volume of ingredients approximately 4/3 interior flask size is prepared from the first coat recipe.

(Figure 21)

This step is critical and requires the aid of an assistant. The wax model is inverted and the plug on the figure's head is fitted to the gas escape hole in the bottom of the flask. While one person holds the model in place, another pours thin investment until the flask is filled. The model is gently agitated and the flask tapped to aid in the complete take of investment.

(Figure 22)

The complete invested form or mold is shown. The large wax opening in the center will serve as the pouring cup. The smaller openings on either side will be auxiliary vent holes for gas escape in the metal pouring stage.

(Figure 23)

As outlined in figure 14 the dry mold is positioned to permit the optional steam-out phase permitting reclamation of much of the wax, prior to burn-out.

Before re-use of this wax it must be slowly heated until any water content, absorbed from the steam, is eliminated.

V. Burn-out Mold

Burn-out is the term applied to complete wax elimination from the mold. This must be done in a kiln capable of reaching temperatures of at least 500° F. Project sizes are limited to kiln capacity. If one has used proper waxes there will be no danger of fire when it becomes superheated in this firing stage. Commercial sculpture wax will leave no residue within the kiln.

(Figure 24)

This homemade kiln has a capacity of approximately thirty-six cubic feet and presents no space problem in handling a number of molds. Most public school kilns are considerably smaller, averaging under four cubic feet in capacity. This must be considered in establishing maximum invested project sizes. It is relatively simple to construct a large kiln but rather impractical in the public school situation when its use would be quite limited.

The molds are stacked upon one another with openings faced down. This will insure complete wax elimination. Forms on the bottom of the kiln are propped on fire brick to allow air space to their openings.

(Figure 25)

A mold known to have wax remaining after steam-out has an angled iron trough placed at its opening continuing through the kiln door. A pail beneath will reclaim this wax during the preliminary low heat firing.

(Figure 26)

The door of the kiln is partially sealed. Initial firing will be slow and temperature increase gradual, permitting vapor elimination from the molds without explosion. After several hours of firing, gradually reaching temperatures of approximately 300° F, the free water will have been eliminated from the molds. The kiln door may now be sealed tight and the heat raised to approximately 500° F. This procedure will remove the combined water from the plaster in the mold. Several more hours are required for this step. The molds are dry when they are of even color and weight; the required firing time then being variable with the size of kiln and mold.

With experience the firing process may be speeded up by quicker and higher increases in temperature, but this will require closer supervision. The kiln temperature may be gradually increased safely up to 1500° F without harming the molds. Temperatures above this point are likely to result in explosion of the plaster and subsequent damage to the kiln. Time is a variable factor but a six hour burn-out is normal. It is of prime importance in any case that all water content be removed from the molds, since the following metal pouring sequence could otherwise either result in mold explosion or a distorted casting. Metal will not adhere to moist mold surfaces.

Best castings are achieved when the molds are still hot. It is also safest this way as moisture will not be present in the molds. For this reason planning in correlating burn-out and casting times is a factor of great importance. The molds should not be chilled suddenly; cracking could result. It is best to open the kiln door partially at least one hour before casting to allow the molds to adjust to the ever cooling atmosphere. Metal melt should begin at this same time depending on the particular metal and quantity of melt.

Should school schedules interfere with burn-out and casting during the same day, molds may be kept in the sealed kiln and reheated the following morning to a temperature of at least 500° F. They may then be removed and prepared for casting.

Protective clothing is necessary in removing the hot molds from the kiln. They must be handled carefully as they could otherwise easily crumble, ruining chances for the final steps of this unit.

VI. Set Mold In Sand Or Earth Base

(Figure 27)

A hot mold has been gently set in a protective tamped sand and/or earth environment with the openings facing upward. This example utilizes a common garbage can. The earth is impacted tightly around the mold until level with the top. Should the mold react to the molten metal it will be stabilized by this packed environment.

(Figure 28)

The molds are prepared in earth surroundings. The pouring cups are covered to prevent entrance of foreign material.

VII. Pour Molten Metal

(Figure 29)

The crucible is placed in the furnace with adequate metal for the melt. Previously determined ratios of wax to metal have been implemented (see Spruing and Venting the Model). Many types of metal melt furnaces are available commercially. However one like this can easily be constructed by lining the interior of a disgarded oil drum with firebrick. A commercial blower is used to achieve the necessary high temperatures from the natural gas source. (See Appendix E)

(Figure 30)

The blower is lined up with the hole in the side of the furnace. The gas is turned on and ignited at the tip of the blower. Then the blower itself is turned on. The furnace cover shown was constructed of firebrick bound by an iron rod and adjustable screw joint. As further illustrated in this example, sulfurous and other toxic fumes require adequate ventilation.

(Figure 31)

A period of approximately two and one-half hours has elapsed before this particular load of sixty pounds of bronze is ready to pour. When the metal is judged ready, tested with a lance pyrometer, the blower and gas supply are turned off. The proper commercial flux is then been sprinkled into the crucible. The crucible is now being raised from the furnace by qualified personnel using tongs and wearing proper safety gear. Smaller loads and metals with lower melting points will greatly simplify this procedure.

(Figure 32)

The crucible is set on firebrick or asbestos and quickly transferred to a two-man shank or crucible carriage. The slag is skimmed off into an earth depression. The clean molten metal is now being poured into a mold.

(Figure 33)

Cast metal in plaster-silica molds remains liquid for a longer period of time than in sand molds. The molds should be undisturbed for at least one hour, allowing the metal to set completely. However if left for a prolonged period of time, separation of investment and metal will be more difficult. The metal will also be inflexible when removing sprues and vents from the intended cast form.

VIII. Remove Investment, Sprues And Vents

(Figure 34)

The cast positive forms are now separated from the soft powdered investment. Hammers and improvised tools are used. The metal is immersed in water when it has cooled to the point where the sudden chilling will not create a thermal strain. The metal could crack if immersed too quickly. When the hand placed above the metal senses little heat, it is ready for immersion. The casting is then scrubbed and wire brushed.

(Figure 35)

Prior to finishing the castings, all salvaged dry investment is crushed and strained through mesh to be used as luto in further projects.

(Figure 36)

All sprue and vent networks are now removed with the aid of a hack saw, hammer and chisel.

(Figure 37)

The freed castings and residual metals are separated and cleaned. Residual metal will be stored for future casting.

IX. Grind and Chase Casting Surface

(Figure 38)

A casting is pictured with a variety of tools used in finishing. After wirebrushing, chasing tools, chisels, files, pliers, and an electric grinder will remove imperfections from the form. Some complex forms may require sandblasting. This can be done by a commercial concern for a nominal sum. The resultant surface of the cast in this instance may be even and monotonous. This can easily be overcome in the patina stage.

X. Patina

When the metal casting has been polished to the point where all blemishes are removed, it is ready for surface coloring or patining. A variety of chemical agents can be used for different color reactions to the metal. Specific formulas as tested by Clarke* are listed in Appendix G.

It is not unusual for the true color to take its full effect after a period of one to two hours following chemical application. Dry chemical pigments may be applied as well as those mixed with water for particular effects. The composition of the metal used in the cast will greatly influence the resultant color. As a general rule, metals with a high copper content will take color more easily. Metals with high zinc content, such as brass, will discourage patining.

It is important prior to patining that the metal cast be thoroughly cleaned, removing any oils and oxides from the surface. This can most often be simply done by rinsing the work with soap and water. Stubborn stains may be removed with ammonia or commercial pickle preparations such as Sparex #2.

Patining may be accomplished, depending on the agents used, by either heating the cast or formula or direct brushing to the cold work. At times it is most convenient to

---

*Dr. Carl Dame Clarke, Metal Casting of Sculpture (Butler, Md: Standard Arts Press, 1948), 170pp.

immerse the cast in the formula. Patina formulas requiring heat may be best applied when the metal is hot enough - when the solution sizzles on application. Butane cylinders, gas-air or oxy-acetylene torches may serve as heat sources. When dry, the patining is done or ready for further applications.

(Figure 39)

Several castings have been cleaned and imperfections removed. They are now prepared for surface coloring or patining. The head has already been treated with a solution of chemicals and water (see Appendix G). Normally only the metal surface is affected. Thus to preserve the finish, in handling and exposure to the atmosphere, a coating of car or furniture wax, varnish, oil or laquer may be desirable.

XI. Mount on Base

We are now ready for the final step in this process - preparing the cast for display. Some forms will have been designed as self supporting and require little further attention other than perhaps a felt pad bonded to the under side with household glue. This will prevent furniture scratching when the works are displayed in the home. Other forms will require a base bond to them before they will be termed complete. The following five examples will illustrate some of the possibilities of this last phase.

(Figures 40, 41)

This finished work was conceived as a free standing utilitarian piece. The final phase demanded only that the underside be filed flat. A piece of felt was then glued to this surface to facilitate its table-top use as a container. This work is approximately five inches high, six inches long and three inches wide.

(Figure 42)

A hole was drilled in the bottom of this cast and tapped. A piece of stone was then cut on a diamond saw and drilled with a masonary bit. The metal and stone were then screwed together. This piece is approximately nine inches high, three inches in base length and two inches in base width.

(Figure 43)

This piece was cast with a small tubular bottom appendage. A piece of stone, cut on a diamond saw, was drilled to accept this projection. The bond was secured with expoxy glue. This project is six and one half inches high. Width is two and one-half inches and length is three inches at the base.

(Figure 44)

This piece was conceived as being self supporting. A metal slab protrudes from the base of the neck providing adequate balance. A felt pad was glued to the underside of this slab to facilitate its placement on a variety of home surfaces without scratching them. The maximum dimensions of this project are: height - nine and one half inches; width - nine inches; length - seven inches. The bronze figure weights thirteen pounds, thus being a maximum sized project for classroom involvement where many projects must be cast.

As you have seen, this waste mold, lost wax metal casting process can be quite technical but it need not be extremely so. Material requirements as listed in Appendices B, D and G are many. Availability of some of this material may be difficult or expensive in some locales. Time spent on a project of this sort again varies but could well consume up to five weeks of normal fifty-minute class periods. Modular scheduling would considerably reduce this factor. The instructor must be competent and the student serious for this operation to be conducted in safety and to result in success. The following is an approximate time-table of events:

Process	Required Time (Fifty minutes = 1 class day)
Ideation and model construction -	One to Two Weeks
Investment of model -	One Day
Setting and drying of mold -	Three Days
Steam-out (optional) -	Two Days
Burn-out and casting -	One to Two Days
Finishing cast -	One to Two Weeks
TOTAL	Four to Five Weeks

Appendix "A"

The simplified sequence of waste mold metal casting will be illustrated with the aid of an eight part color coded diagram on the following page.

Ex. #1 The wax model is constructed.

#2 The wax model is sprued and vented.

#3 The completed wax assembly is surrounded with investment.

#4 The invested form is heated in a kiln, eliminating the wax, leaving a negative impression.

#5 The burned-out form or mold is inverted, impacted with a sand and earth environment and filled with molted metal.

#6 After cooling the mold is chipped away, freeing the solid metal cast assembly.

#7 The metal replica of the original wax model is separated from the remainder of the cast assembly.

#8 The finished cast is surface colored and mounted on a base if needed.

Appendix "A" (2)

= Wax

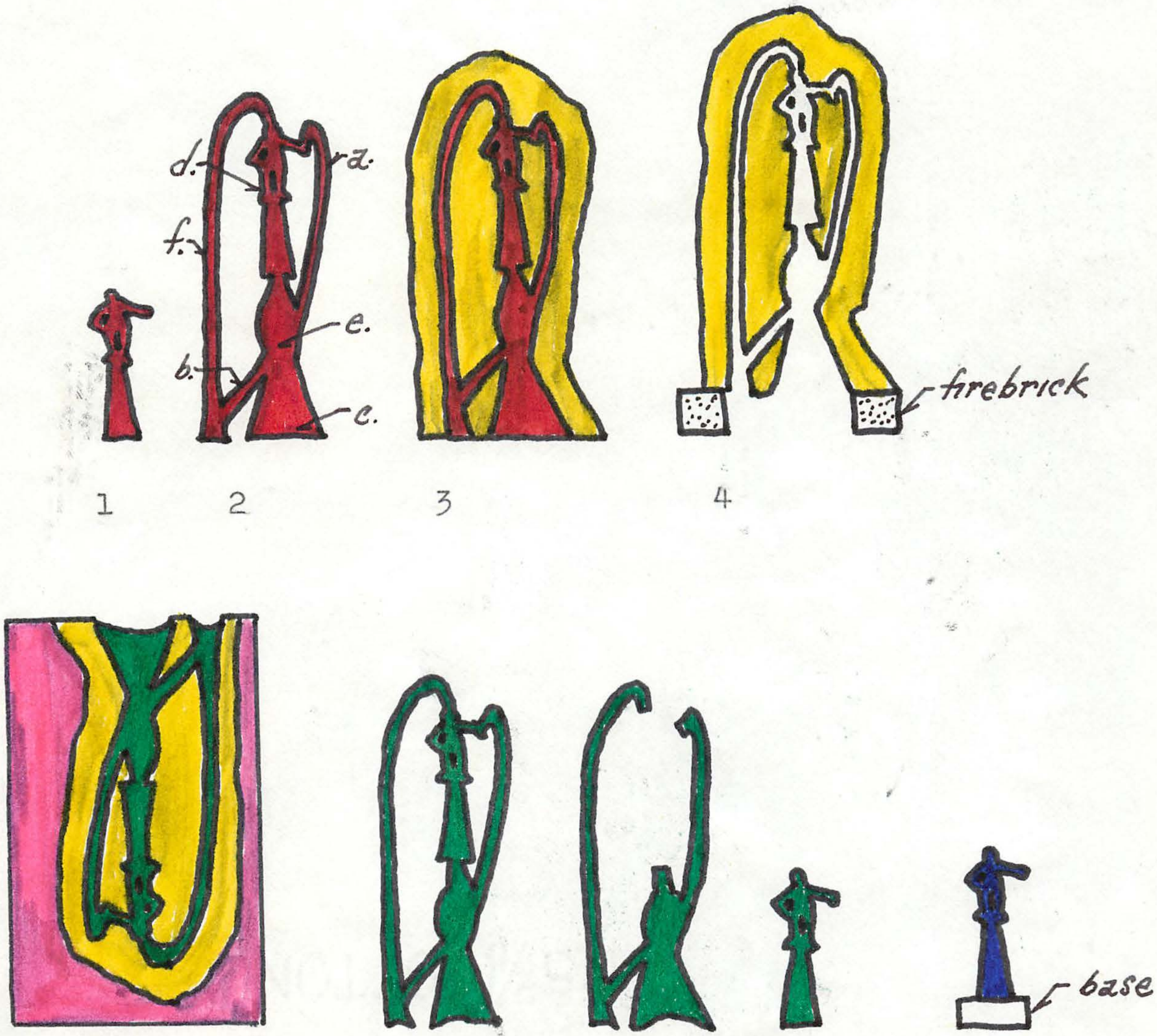
= Investment

= Fine Sand/Earth Impactment

= Metal

= Patinaed Metal

a. auxiliary sprue (if needed)
b. brace
c. main sprue (pouring cup)
d. model
e. reservoir
f. vent (if needed)



1 2 3 4

5 6 7 8

Appendix "B"

Materials Required For This Process

Apron or Coveralls

Sketch Pad and Pencil

Modeling Wax

Wax Modeling Tools

Casting Metal

Green Soap or Debubblizer

Small Brushes

Spatula or Scraper

Investment (See Appendix D)

Electric Hot Plate or Gas Supply

Tea Kettle and Small Rubber Hose

Water Supply

Mixing Bowls

Kiln and Fire Brick

Metal Melting Furnace and Related Equipment

- Crucible
- Crucible Tongs
- Crucible Carriage
- Skimming Tool
- Lance Pyrometer
- Asbestos Gloves and Leg Pads
- Safety Goggles and Face Shields

Dry Earth and Forms to hold impacted Molds

Wash Tub or Deep Sink with Large Trap

Screen Sieve (to reclaim used investment)

Cast Finishing Equipment

Wire Brush

Hack Saw

Metal Chisels

Chasing Tools

Hammers

Pliers

Electric Drill

Drill Bits (Metal)

Drill Bits (Masonary)

Electric Grinder and Burs

Diamond Saw

Screw Driver and Screws

Tapping Set

Safety Glasses

Patining Agents (see Appendix G)

Butane Cylinders, Gas-Air or Oxy-Acetylene Torch

First Aid Kit

Fire Extinguisher

Appendix "C"

GLOSSARY

Anneal - To soften metal by heating evenly and then cooling. This process prevents metal from cracking.

Auxiliary - Additional secondary vents and sprues to facilitate the elimination of gases and the pouring of molten metal.

Burn-Out - The process of melting wax from a mold by heating before casting. It is important to always heat the mold slowly to prevent its cracking and to insure that all wax and moisture have been eliminated.

Casting - The process of pouring molten metal into a mold by gravity, centrifuge or injection. The product of casting is the positive form.

Chasing - The process of indenting lines or evenly texturing a metal surface by tapping with sharp and blunt chisel - like tools.

Core Pins - Pins sunk into the wax model after a hollow has been filled with investment. Enough pin surface is left protruding from the wax to permit an outer investment layer a firm grip. After burn-out the core will be suspended only by these pins. Following casting the pins are sheared off and the forms chased or tapped to disguise their former presence. Patination will further disguise these areas.

Crucible - A pot of some very refractory substance as clay, graphite, porcelain or a relatively infusable metal, used in melting metals.

Debubblize - The process of painting liquid soap on the wax model before using investment, helping to eliminate surface tension and air bubbles.

Fins - Flashing of excise metal on the cast form usually caused by cracked mold.

Flask - A cylinder used in casting to encase the model and investment.

Flux - Liquid or powdered elements which keep metal free of oxidation.

Investment - A mixture of formulated ingredients used to encase the model forming a mold. After burn-out and wax elimination the mold will contain a negative form.

Lost Wax - The term applied to the elimination of a wax model in a mold by heating.

Malleable - Material capable of being altered in form (wax and metal).

Melting Point - The exact degree where metal turns into liquid form.

Minerals - Chemical elements or compounds that occur naturally as a product of inorganic processes (anything not animal or vegetable).

Mixing Acids - Always pour acid into water when preparing patina formulas. The reverse could result in a violent chemical reaction.

Mold - The invested wax model. After burn-out this fired investment has a hollow or negative form. After casting this mold contains the positive form.

Negative - The hollow area in a mold after the wax model has been eliminated in burn-out.

Oxidize - Uniting metal and oxygen to form a residual layer of metal. This is most often used as intentional decoration as patining. However it could also be an unwanted scale that must be filed, buffed or scrubbed from the metal surface.

Patina - Surface coloring of metals by induced mineral action.

Pickle - A mineral solution prepared for cleaning the metal of foreign debris and oxides.

Positive - The original wax model and the resultant form in the mold after being filled with molten metal.

Pouring Cup - The funnel shaped base of the main wax sprue. After burn-out this large hollow is the main entryway for cast molten metal.

Pyrometer - An instrument which records unusually high temperatures beyond the range of ordinary thermometers.

Sculpture - Shaped materials of three dimentional qualities according to the artists wishes.

Shank - An iron crucible carriage used to aid in pouring molten metal.

Sprue - The passageway constructed in the wax assembly to serve as an eventual avenue for cast metal within the mold.

Steam-Out - The process of melting wax from the mold by steam action. This permits reclamation of much of the invested form.

Tempering - The process of hardening metals to varying degrees with heat.

Tongs - Iron clasps to hold the hot crucible or hot metal forms (can be made of other high melting point metal).

Vents - Provided passages in molds to allow locked gases to escape. In simple forms or small forms with porous molds venting is often unnecessary.

Wax - A plastic substance easily molded that cannot be dissolved in water.

Appendix "D"

Investment Formulas

Powdered silica may be difficult or expensive to obtain in some locales. For this reason I have listed a series of variations on investment formulations. Many variations from these alone are possible. All recipes are added to water until evenly creamy.

	AGENTS	PARTS BY VOLUME
1.	Plaster	1
	Silica Sand	1
	Brick Dust (finely ground grog or fire brick)	1
2.	Plaster	1
	Silica Sand	1
	Fine Vermiculite	1
3.	Plaster (Plaster of Paris or Moulding Plaster)	2
	Brick Dust	3
4.	Chrystobalite or Dented Grey Investment	1
	Potters Flint	2
5.	Powdered Dry Asbestos	1
	Plaster	1
	Potters Flint	1

Appendix "E"

Metals And Their Properties

Metal	Melting Point (^oF)	Specific Gravity
Aluminum	1220^o	2.56
Brass	930^o - 2075^o	Similiar to Copper (Varies)
Bronze	572^o - 1926^o	Similiar to Copper (Varies)
Copper	1981^o	8.93
Gold	1945^o	19.36
Lead	621^o	11.37
Pewter	500^o	8.00 (Varies)
Platinum	3224^o	21.45
Silver	1761^o	10.56
Sterling Silver	1640^o	10.40
Tin	450^o	7.29
Zinc	787^o	7.14

Appendix "F"

These are sources of the common casting failures and their causes:

1. Rough surfaces and fins:

   a. Too much water in the investment
   b. Dirt or drops of debubblizer or water on the wax
   c. Incompletely mixed investment
   d. Wax elimination too rapid. Steam causes investment to fracture and explode
   e. Casting metal too hot
   f. Mold heated too high
   g. Vibration for bubble removal too strong or too prolonged
   h. Incoming metal striking a flat surface
   i. Model too close to edges or top of mold

2. Pitted castings:

   a. Metal not completely melted
   b. Too much flux
   c. Dirty metal
   d. Sprues too large or too small or incorrectly placed for rapid entry of metal into the mold
   e. Broken fragments of investment formed during burn-out or casting
   f. Heavily oxidized metal due to incorrect melting and fluxing.

3. Bubbles of metal on the casting:

   a. Air in the investment
   b. Air trapped during the painting of the model
   c. Water or debubblizer drops on wax during painting

4. Oxidized Castings (if not excessive, slight oxidation is normal on all alloys):

   a. Incomplete wax elimination
   b. Metal overheated in the casting crucible

5. Incomplete castings:

   a. Sprues too small
   b. Not enough sprues to extended areas
   c. Too much investment above the top of the model
   d. Mold too cold during casting
   e. Metal not hot enough during casting
   f. Not enough metal

6. Cracks in the casting:

   a. Quenching while too hot (see cooling schedule, page 22), (figure 34)

Appendix "G"

Patina Formulas*

Metal	Color	Agents	Parts By Weight
Bronze	(Copper 85 - 90%, Tin 5 - 7%, Zinc 3 - 5%, opt. lead 5%)		
	Yellow Green	Ammonium Chloride	7
		Copper Acetate	4
		Water	8
	Light Green	Sodium Chloride	5
		Ammonia	4
		Ammonium Chloride	5
		Glacial Acetic Acid	4
		Water	32
	Blue Green	Sodium Thiosulfate	1
		Ferric Nitrate	8
		Water	128
	Antique Gold	Copper Sulfate	12
		Ammonium Chloride	2
		Water	128
	Brown	Potassium Sulfide	1
		Barium Sulfide	2
		Ammonia	4
		Water	400
		Antimony Sulfide, golden	1-2
		Sodium hydroxide (lye)	4
		Water	256
		Yellow barium sulfide	1
		Water	128
		Temperature	150° F
		Copper Sulfate	5
		Glacial Acetic Acid	2
		Sodium hydroxide (lye)	2
		Water	64
		Temperature	160° F
	Brown to Black	Potassium Sulfide	1
		Water	128
		Temperature (darkest up to)	150° F
	Black	Arsenious Acid	2
		Muriatic Acid	4
		Sulfuric Acid	1
		Water	64

*As tested by Clarke
Clarke, Dr. Carl Dame, <u>Metal Casting of Sculpture</u>
The Standard Arts Press, Butler Md: 1948, pp 166 - 169

Patina Formulas

Brass: The formulas listed for bronze are for the most part applicable to brass when used in longer immersion or with increased heat. As brass contains more zinc than bronze it is more difficult to patina. The formulas below are best suited for brass coloration, applied hot or to hot metal.

Metal	Color	Agents	Parts By Weight
Brass (approximately 90% copper, 10% zinc - varies)			
	Green	Sodium Thiosulfate	4
		Ferric Nitrate	1
		Water	64
	Antique Green	Ammonium Chloride	14
		Ferric Chloride	3
		Sodium Chloride	8
		Verdigris Powder	8
		Potassium Bitartrate	4
	Dark Green	Copper Nitrate	1
		Ammonium Chloride	1
		Calcium Chloride	1
		Water	32
		Copper Sulfate	8
		Ammonium Chloride	4
		Sodium Chloride	4
		Zinc Chloride	1
		Glacial Acetic Acid	3
		Water	128
	Blue	Sodium Thiosulfate	4
		Lead Acetate	3
		Water	64
	Brown	Antimony Sulfide, Golden	1
		Sodium hydroxide (lye)	1
		Water	32
	Brown to Black	Copper Sulfate	1
		Potassium Chlorate	1
		Water	16

Metal	Color	Agents	Parts By Weight
Brass	Black	Copper Carbonate	2
		Ammonium Hydroxide	4
		Sodium Carbonate	1
		Water	32
Lead	Black	Hydrochloric Acid	4
		Water	1
Silver	Gray to Black	Potassium Sulfide	1
		Water	128
		Ammonium Sulfide	1
		Water	128

Appendix "H"

Slide Illustration Outline

Subject		Figure Number In Text
1.	List of sequences in Metal Casting	1
2.	Construction of the Wax Model	2, 3
3.	Spruing and Venting the Model	4, 6
4.	Debubblizing the Model	7
5.	Basic Formulas of Investment	8
6.	Investing the Model	9 - 22
7.	Steam-Out of Mold	14, 23
8.	Burn-Out of Mold	24, 26
9.	Impacting Mold in Earth Environment	27, 28
10.	Molten Metal Gravity Casting Procedures	29 - 33
11.	Removal of Casting from Mold	34
12.	Reclamation of Mold Material	35
13.	Removal of Sprues and Vents from Casting	36, 37
14.	Finishing the Surface of Casting	38
15.	Induced Surface Coloration of Casting	39
16.	Completed Casting	40 - 44

BIBLIOGRAPHY

Choate, Sharr. Creative Casting. New York: Brown Publishers, 1966, 209pp.

Clarke, carl Dame. Metal Casting of Sculpture. Butler,Md.: The Standard Arts Press, 1948, 170pp.

Von Neuman, Robert. The Design and Creation of Jewelry. New York: Chilton Company, 1961, 228pp.